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Final Report

AN EXPERIMENTAL STUDY OF THE CATARACTOGENIC EFFECTS OF MICROWAVE RADIATION

TECHNICAL DOCUMENTARY REPORT NO. RADC-TDR-64-273

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Display Techniques Branch
Rome Air Development Center
Research and Technology Division
Air Force Systems Command
Griffiss Air Force Base, New York

Project No. 5545, Task No. 554502

(Prepared under Contract No. AF 30(602)-3087 by the Zaret Foundation, Inc., Scarsdale, N.Y. with the cooperation of Department of Ophthalmology, New York University School of Medicine, New York, N.Y. and Electrophysics Department, Polytechnic Institute of Brooklyn, Farmingdale, N.Y.)

All experiments described in this report involving animal subjects were conducted according to the "Rules Regarding Animal Care," established by the American Medical Association.

FOREWORD

The investigation reported herein was undertaken in May, 1963, under contract AF30(602)-3087 with the Rome Air Development Center, Air Force Systems Command, United States Air Force, Griffiss Air Force Base, New York.

The primary interest of the U. S. Air Force with respect to this contract was to determine a method for investigating the cataractogenic effect of microwave radiation in order to provide optimum safety from the hazard for military personnel without unnecessarily restricting the operational capability of the microwave generating equipments.

The first phase of this study has been concluded. What remains to be done is to apply the methodology developed in this study on a broad base in order to define the parameter of hazard in relationship to the operating characteristics of military equipments currently in use and contemplated for the near future.

This research program has been conducted under the general supervision of Milton M. Zaret, M. D., Principal Investigator. Associated with him for various phases of this work were Mr. Gerard M. Grosof, Dr. Herbert Schmidt, Mr. Harold S. Lappin, and Mrs. Claire Davis Zaret. In addition acknowledgement is gratefully made to Professor Goodwin Breinin, Head of the Department of Ophthalmology, New York University School of Medicine and Professor Saul Rosenthal, Head of the Electrophysics Department, Polytechnic Institute of Brooklyn for their own efforts as well as the staff support received from their departments. In addition, credit for the material presented in SECTION III MICROWAVE FACTORS belongs to Professor Rosenthal.

AIR FORCE, ESD, N.Y., [illegible]

ABSTRACT

An exploratory investigation was performed to determine the applicability of spectrophotometric analysis to the measurement of cataractogenesis. It was found that standard spectrophotometric techniques cannot be utilized for this purpose but that a new method for performing spectrophotometry in the living eye, which is known as retinal reflection densitometry, shows promise of being capable of performing this task.

A methodology is presented for an applied research investigation of cataractogenesis in order to delineate the parameters of personnel hazard associated with microwave environments. The biological and microwave experimental protocols as well as the relationship of laboratory induced cataractogenesis to the clinical study of human microwave cataracts are discussed.

PUBLICATION REVIEW

This report has been reviewed and is approved. For further technical information on this project, contact William J. Doherty, EMEDI, Extension 3158.

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TABLE OF CONTENTS

EVALUATION

The principal objective of the RADC Microwave Hazards Program is to establish and validate a safe and practical limit for personnel exposure to microwave radiation. Since it is generally acknowledged that the crystalline lens is the human structure most susceptible to microwave induced thermal injuries, it is essential that the response patterns of lenticular tissue be characterized over a broad range of frequencies and intensities.

An outstanding problem encountered in the study of optical changes is the lack of standard methods for describing objectively the extent of opacity development. Currently, the assessment of radiation effects on the lens system is accomplished by slit lamp examination, and ophthalmological measures are based on subjective estimates which vary widely with respect to the identification and specification of cellular damage. Recognizing the need for objective measurement and firm criteria, this study was undertaken to determine the feasibility of applying spectrophotometric techniques to the problem of detecting and quantifying small changes in lens tissue transparency.

The significance of this study is contained principally in the demonstration that standard spectrophotometric techniques are not directly suited to the novel application of lens damage assessment. Concomitantly, however, it is strongly suggested that a recent development in spectrophotometric dosimetry termed "the retinal reflection technique" will perform exactly the measurement function we envision. Moreover, it has been shown that this instrumentation is amenable to coupling with existing photographic techniques so that opthalmological findings may be documented immediately.

The accomplishment of this exploratory study concludes all work programmed under Task 554502, "Studies of Microwave Induced Lenticular Opacities." No follow-on research is planned since all remaining funds have been assigned to a higher priority biomedical problem. The final investigation will be completed during September 1965 at which time the RADC Microwave Hazards Program will be terminated.

William J. Doherty

WILLIAM J. DOHERTY
Project Engineer
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I

INTRODUCTION

This investigation comprised an exploratory probe which was undertaken in cooperation with the Department of Ophthalmology, New York University School of Medicine and the Electrophysics Department, Polytechnic Institute of Brooklyn.

The experimental studies were oriented towards making quantitative determinations of the cataractogenic effects of microwave energy. The study included, but was not limited to, the following research tasks:

a. Development of a spectro-photometric technique to provide standardized measurements of the degree of cataract formation in the eyes of laboratory animals.

b. Development of a photographic technique to document the spectro-photometric findings.

c. Adapt the photographic technique to the human eye so that biological assay of the animal eye may be related to man.

The eyes of laboratory animals were exposed to controlled radiation fields in order to produce cataracts and the isolated and combined influences of such microwave parameters as power density, frequency and wave form characteristics including cw operation were studied. Human microwave cataract data was obtained and compared to the experimental findings.

Analysis of the results of this investigation indicates that a scientifically valid basis can be established for evaluating the human cataractogenic potential of any given microwave environment. This can be accomplished only by properly segregating and evaluating each of the varying factors to be considered and by properly designing an experimental protocol so as to investigate each of these factors in a methodical manner.

This study demonstrated not only that it is feasible to define the parameters of microwave cataractogenesis but also that a pre-requisite for such an undertaking is the establishment of a joint interdisciplinary approach. It is essential for the microwave physicist to have a complete and flexible equipment capability in order to properly support the ophthalmic investigators.

II

CATARACT FACTORS

The lens of the eye is a transparent, biconvex tissue, enclosed in a thin, transparent capsule. The lens capsule is a relatively homogeneous and structureless elastic membrane. Ordinarily, this membrane cannot be identified by ophthalmic examination but it becomes visible in some people employed in environments of excessive infra-red radiation and as such is recognized as the earliest finding of thermal injury to the lens.

The lens substance itself is composed of cells; namely, epithelial cells and lens fibres. Epithelial cells at the equator of the lens undergo metaplasia and hyperplasia to form enlarged lens fibres. As new fibres are formed, the elongated ends extend towards the anterior and posterior poles of the lens exteriorly to the older fibres which are compressed centrally by this process and with time the older fibres become sclerosed. The central zone of the lens (the nucleus) can be distinguished from the peripheral zone (the cortex) by examination with a slit-lamp; however, the individual cells of the lens cannot be identified by this means.

The lens substance is normally in a state of optical transparency. Any loss in transparency whether localized to a given region of the lens or generalized throughout the substance of the lens, is termed opacification. Opacification can be present without a measurable loss of visual acuity. However, whenever opacification interferes with visual capability, this is termed cataract.

The process of cataract formation proceeds in two stages. Initially, the lens imbibes fluid and thus becomes edematous (hydrated) which results in a swollen (intumescent) physical state. In the second stage, after hydration has been present for a period of time, the protein molecules of the lens undergo chemical change (coagulation). The process of hydration is reversible whereas the process of coagulation is irreversible. Furthermore, coagulation does not take place except in the presence of hydration.

A technique was developed whereby the lens within its intact capsule was excised from the laboratory animal eye and placed in a physiological solution resembling intra-ocular fluid. Providing the capsule retained its integrity, it was possible to maintain such a lens in a transparent state for the duration of the laboratory day at room temperature. Heating the solution containing the lens resulted in the production of cataractous changes within the lens substance.

By heating the lens in a non-agitated physiological solution (average temperature of approximately 50° Centigrade) for a few minutes a temperature gradient could be produced across the lens. This was accomplished by positioning the lens so that its posterior surface was close to the thermal source and its anterior surface was away from the thermal source. Under these conditions, a partial cataract was produced in the posterior portion of the lens without producing any discernable change in the anterior portion. No attempt was made to determine the threshold temperature at which this phenomenon would take place. Instead, only the temperature gradient principle was tested because it has been assumed that, if an intact eye was heated uniformly, a temperature gradient would be induced across the lens.

By heating a lens in a solution uniformly maintained at a constant temperature the results will vary according to the temperature level maintained and the time-duration of the exposure. When heated above 60° C for a number of minutes, all lenses become cataractous. At 50° C, opacification was noted to begin after 35 minutes of exposure and a complete cataract was formed after 65 minutes of exposure. At 45° C, opacification began at the periphery of the lens after 45 minutes of exposure but it was not complete even after 5 hours of exposure at which time the experiment was terminated.

Experimentation with the early stages of thermally induced lens injury revealed that, in the earliest stages, a diffuse faint opacification occurred peripherally, immediately adjacent to the surrounding capsule. Concomitantly, the entire lens swells so that it becomes intumescent. At this stage of cataractogenesis (hydration) the opacification is reversible in that the lens becomes transparent when pressure is applied to its capsule, a process which forces the excess fluid out of the lens. However, after the diffuse faint opacification was present for several hours, pressure applied to the capsule could no longer make the lens transparent, but, instead, the process of opacification had become irreversible (coagulation).

These in vitro experiments of thermally induced cataractogenesis were undertaken in association with a study (1) to determine the feasibility of applying spectrophotometric examination techniques in order to provide a measurement of the degree of cataract formation, (2) to develop a photographic technique to document the spectrophotometric findings and (3) to adapt the photographic technique to the human eye so that biological assay of the animal eye may be related to man.

In order to perform spectrophotometric analysis of the in vitro animal lens, a special animal lens holder was required not only to position the lens properly in the path of the spectral beams but also to flatten the anterior and posterior convex surfaces of the lens so as to make these

surfaces aplanatic. This latter procedure, however, compresses the lens surfaces and the resultant pressure induces a forced dehydration of the lens. Under this circumstance, the process of cataractogenesis cannot proceed in a normal manner. Therefore, it was found that ordinary methods for performing spectrophotometry cannot be applied to the measurement of cataractogenesis.

Fortunately, however, Dr. Robert A. Weale of the Institute of Ophthalmology, London, England has developed a new apparatus for performing in vivo as well as in vitro spectrophotometry of the eye. His instrumentation is unique as it passes spectrally pure monochromatic beams of light (covering the spectral distribution for light) of known intensity into the eye and photometrically measures the light returning out of the eye, the emergent light having been reflected from the retina. Furthermore, he has designed and incorporated an associated optical train which obviates the need to interfere with the ocular optics so that it is not necessary to make the animal lens aplanatic. This new technique is known as retinal reflection densitometry. Dr. Weale✓ discovered that should early stages of edema and coagulation take place in the intervening transparent ocular tissues, then his spectrophotometric readings behaved as if a filter had been placed in the optical path and he termed this the "grey filter effect". This grey filter effect is precisely the type of biological reaction that it is desired to measure in the lens. Its measurement would be an extremely sensitive indicator of lenticular injury.

Thus, the state-of-the-art studies of reflection densitometry show promise that this spectrophotometric technique can be adapted to the study of cataractogenesis in the living eye, human as well as laboratory animal. Because of this as well as the emerging importance of retinal reflection densitometry as an investigative instrument, our laboratory has begun fabricating an improved model of Dr. Weale's prototype reflection densitometry apparatus.

As this type of examination can be correlated to specific ocular tissues by means of the Zeiss Retinal Camera, we proceeded to develop a method of utilizing this instrument to measure the degree of cataract formation in the in vitro lens. This particular camera can also be operated so as to photograph the in vivo lens within either the animal or human eye. Therefore, by developing a photographic technique to measure the degree of cataractous change as related to a loss of image resolution capability in the in vitro preparation, comparison of the in vivo

✓R.A.Weale;An Early Stage in the Pathology of Photocoagulation,-Am. J. Ophthal. 53:665(1962)

photographs to the in vitro photographs would permit a measurement of visual loss. This was accomplished by photographing the lens against a graph paper backing.

A series of such photographs was taken utilizing lenses which demonstrate various stages of opacification. When the lens is transparent, the graph paper forms a sharp image on the photographic film. When the lens has an early stage of cataract formation, there is partial interference with the image formation and the graph paper appears to be out of focus and seen as if viewed through a mist. When the lens has an intermediate stage of cataract formation, very little of the graph paper pattern can be recognized. When the lens has a fully developed cataract, it is completely opaque and no image is transmitted.

Concomitantly with the development of a spectro-photometric technique (Retinal Reflection Densitometry apparatus) and a photographic technique (adapted Zeiss Retinal Camera) to measure the degree of cataract formation, to document the finding and to relate it to findings in the animal or human eye in a living state, exploratory microwave exposure experiments were undertaken.

III

MICROWAVE FACTORS

The Polytechnic Institute of Brooklyn, through its Electrophysics Department and at its Long Island Graduate Center in Farmingdale provided the controlled microwave environments utilized in this investigation. The work represented an introductory effort designed to be expanded later into a considerably more intensive program. On the basis of the information and experience obtained from this pilot study, it was hoped that it would be possible to determine the long range requirements of the microwave facility as well as the problems associated with the particular techniques needed for precise measurements.

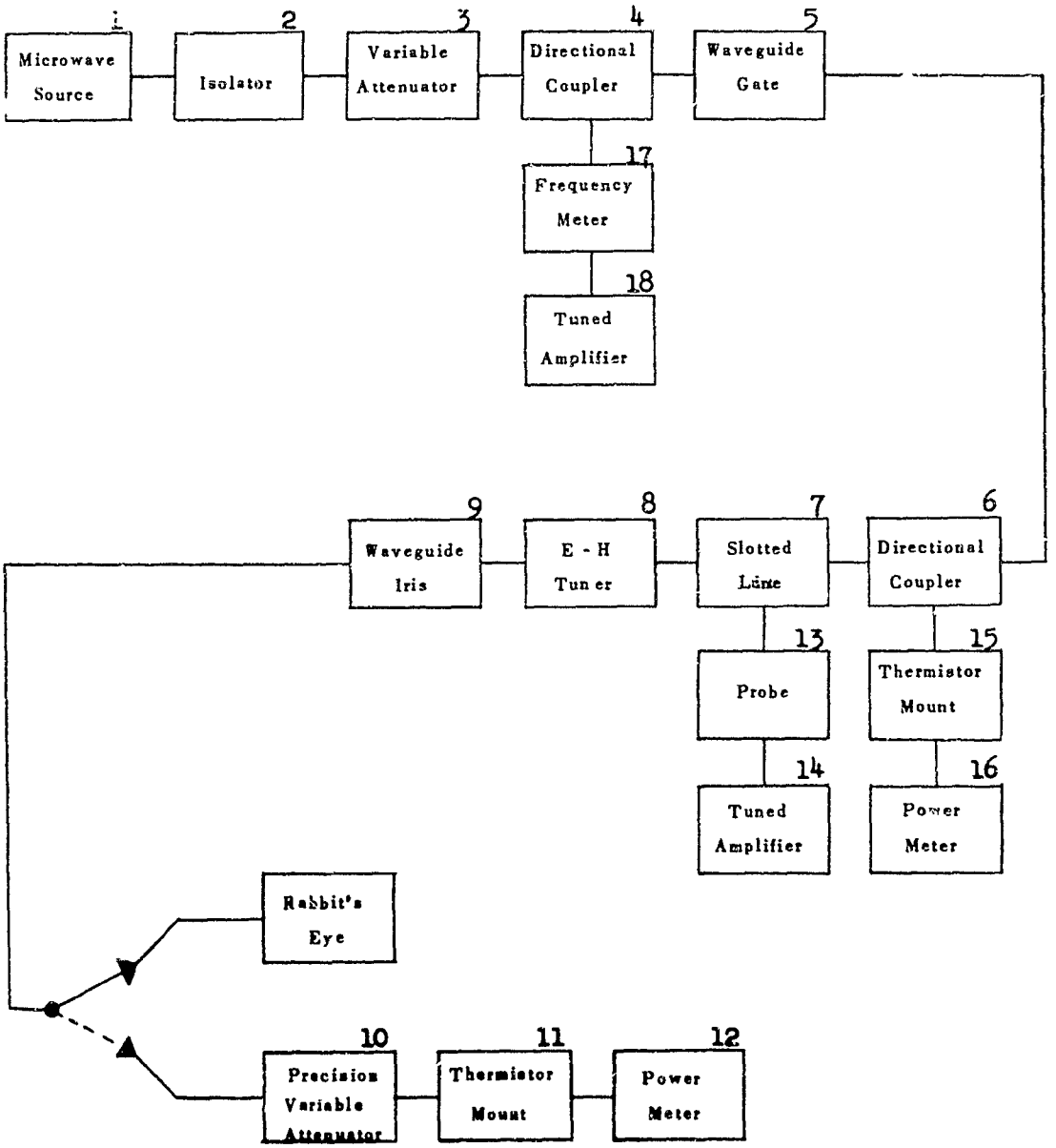
The goals of the project were relatively limited. They were: first, to establish microwave techniques for irradiating rabbit eyes with known amounts of power; and, second, to provide actual acute exposures of rabbit eyes to levels of radiation that would induce cataractogenesis. Precise knowledge of the field characteristics was essential and it was requisite that great flexibility be permitted in altering the emission characteristics of the microwave generating equipment.

Frequencies near 5500 megacycles/second (5.5 Gc) in C-band were used. These frequencies were chosen since there exists at the Long Island Graduate Center of PIB a C-band equipment installation that is highly flexible. It is capable of providing varying acounts of both CW and pulse power over a wide frequency range for a variety of pulse widths, repetition rates and average powers.

It was decided to use the "closed waveguide system" of irradiating eyes[1] since this would provide a more accurate determination of the power absorbed by the eye than open systems. Since acute exposures were desired, transmitting the microwave power directly to the eyes provided maximum flexibility and experimental confidence. The method includes the eye as part of a microwave "closed" system with a source at one end of a waveguide transmission line and the eye as a termination at the other end. It allows for the delivery of a specific amount of microwave power to the termination with a reasonable certainty that it is being absorbed by the eye. This permits a comparison to be made of the amounts of power at different frequencies required to produce the cataractogenic effects of interest.

(1) Russell L. Carpenter, "An Experimental Study of the Biological Effects of Microwave Radiation in Relation to the Eye", Report on Contract No. AF41(657)-86 for Rome Air Development Center, Feb.28, 1962, RADC-TDR-62-131, TUFTS UNIVERSITY, Dept.of Biology, Medford, Mass.

A block diagram of the experimental system is shown below. This is followed by a list of the particular items of equipment used; a discussion of the experimental technique; and, finally, a step-by-step outline of the experimental procedure.



List of Microwave Equipment

1. Microwave Source — Signal Generator HP Model 618B
   +Traveling Wave Tube Amplifier
   Eimac Model EM-1015, 2-5 Watt CW,
   4-8 Gc
   +Traveling Wave Tube Amplifier
   Sperry Model STC 152, 2 KW Peak,
   .002 Duty Cycle, 5.4-5.9 Gc
2. Isolator PRD Model 1205
3. Variable Attenuator FXR Model 151 A
4. Directional Coupler 30DB Sperry Model 321
5. Waveguide Gate PIB
6. Directional Coupler 30 DB Sperry Model 321
7. C-band Slotted Line PIB
8. E-H Tuner PIB
9. Iris, 1/2 inch Diameter Aperture PIB
10. Precision Variable Attenuator PRD 170B
11. Thermistor Mount HP Model 478A
12. Power Meter HP Model 431A
13. Probe PRD Model 250
14. Tuned Amplifier HP Model 415A
15. Thermistor Mount HP Model 478A
16. Power Meter HP Model 431A
17. Frequency Meter Sperry Model 705
18. Tuned Amplifier HP Model 415A

HP=Hewlett-Packard Co., 1501 Page Mill Rd, Palo Alto, Calif.
FXR=FXR, 25-26 50th St., Woodside 77, N.Y.
PRD=PRD Electronics, Inc.,202 Tillary St., Brooklyn 1 NY
Sperry=Sperry Microwave Electronics Co.,Clearwater, Fla.
Eimac=Eitel-McCullough, Inc., San Carlos, Calif.

Description of Experimental Technique

A detailed step-by-step outline of the experimental procedure is given later.

First, however, a brief description is given of the experimental technique using the equipment illustrated in the block diagram:

To the end of the waveguide system; that is, to the output flange of the E-H tuner, is fastened an iris cover plate. The latter consists of a thin (.005 inch thick) metal disk in the center of which is located a 1/2-inch-diameter circular aperture. The E-H tuner is adjusted so that none of the input power is reflected back toward the microwave source. With the waveguide gate closed, the anesthetized rabbit is positioned so that its left eye protrudes somewhat through the aperture into the waveguide. When the gate is opened, the rabbit's eye is irradiated with microwave energy. By a fairly simple method, it is possible to measure the power actually absorbed by the rabbit's eye. The frequency and power level are continuously monitored by the use of two directional couplers (items 4 and 6), each of which serves to sample about 1/1000 of the power in the main waveguide line.

The iris cover plate almost completely short-circuits the wave-guide transmission line. The 1/2-inch-diameter aperture (area 0.196 $in.^2$) is the only opening at the end of the relatively large waveguide (inner dimensions 1.872 inches x 0.872 inches; area 1.63 $in.^2$). Since the aperture area is only 12% of the waveguide cross-section, it is reasonable to suppose that, without any kind of matching device, only a very small portion of the microwave energy incident on the iris plate is actually transmitted through the hole. In fact, at 5.5 Gc, the iris produces a standing wave ratio inside the rectangular waveguide of 115, which implies that only 3.4% of the incident power would normally be radiated out of the hole into the air. When the rabbit's eye is present, it is believed that the standing wave ratio is somewhat lower, although this was not measured. In any event, the use of an E-H tuner was necessary. An ideal E-H tuner, without any losses of its own, is capable of matching the iris to the waveguide so that all of the incident power is transmitted out of the hole into the air, or into the rabbit's eye. In this ideal case, to determine the power absorbed by the eye, it would be necessary merely to determine the incident power in the waveguide, a very simple measurement. Actually, the E-H tuner does indeed have substantial losses when forced to match very large standing wave ratios; in fact, the insertion loss of the E-H tuner-iris combination was measured to be 3-3.5 db.

Several methods are available to determine the power

absorbed by the eye. One method would be to measure the incident power in the waveguide, and then to reduce this value by the insertion loss of the tuner-iris combination. The assumption is made here that the slight retuning of the E-H tuner to re-obtain a matched condition with the rabbit's eye present does not change the previously measured insertion loss. A second method, the one actually used, consists of measuring the power transmitted through the iris into a terminating section of waveguide (items 10 and 11), and assuming that this same amount of power is absorbed by the rabbit's eye when the E-H tuner is reset for a match while the incident power level is kept the same. The error involved here was estimated to be small, and was tolerated in the interests of economy and expediency.

Because the iris plate was only .005 inch thick, it had a tendency to bend and buckle. To prevent this, the iris plate was placed between the E-H tuner output flange and a thick cover plate with a much larger hole cut in its center. A thin piece of transparent plastic was inserted between the two cover plates. This served two purposes: it prevented excessive abrasion of the cornea of the eye by the sharp edge of the iris; also it prevented saline solution, frequently applied to the exposed eye to prevent drying of the cornea, from leaking into the waveguide system.

It is recognized that a redesign of the test section would be quite helpful if the program is continued. For example, one simple method of improving the test section would be to taper down both waveguide dimensions so that the iris area becomes a substantially larger portion of the waveguide cross-section than it is at present. Calculations were made indicating that an optimum taper would reduce the iris standing wave ratio to a value below 40. This would reduce the insertion loss of the E-H tuner and would reduce the measurement error. Additional experiments could be carried out to test the accuracy of the method described; that is, to test whether the same amount of power is transmitted to the eye as is transmitted through the aperture with the eye absent. These experiments might be performed using an electrical model for the eye. Perhaps some other simple method to improve the test section is possible that is not apparent at present. For this reason, consideration should be given to other methods of matching to the rabbit's eye.

Experimental Technique

The experimental procedure used is detailed below in step-by-step fashion. The numbers in parentheses refer to corresponding ones on the block diagram.

(a) The C-band microwave source (1) was adjusted to a frequency of about 5.5 Gc, and the frequency was subsequently monitored by use of the wavemeter(17).

(b) The precision attenuator (10) was set for an attenuation of 30 db so that the power entering the attenuator would be, conveniently, exactly 1000 times the power indicated by the power meter (12). The E-H timer (8) was then adjusted until a maximum amount of power was transmitted through the 1/2 inch iris aperture (9); this was indicated by a maximum reading on the power meter (12). At the same time, this adjustment succeeded in reducing the standing wave ratio observed in the slotted line (7) to a value of about 3 or lower.

(c) The E-H tuner (8) was slightly readjusted until the standing wave ratio was near unity (1.0-1.08).

(d) The variable attenuator (3) was set so that the power entering the precision attenuator was equal to that intended for irradiating the rabbit's eye.

(e) The reading on the other power meter (16) was then observed and recorded for monitoring purposes.

(f) The attenuation introduced by the variable attenuator(3) was increased to a maximum; the precision attenuator (10), thermistor mount (11) and power meter (12) were disconnected from the remainder of the equipment; the anesthetized rabbit was positioned so that its left eye protruded into the 1/2 inch diameter iris aperture (9) at the end of the waveguide system; finally, the power level was increased by setting the variable attenuator (3) until there was just enough power in the slotted line (7) to give a convenient reading on the probe (13) output meter (14).

(g) The E-H tuner (8) was readjusted until a match (1.0-1.08) was obtained in the slotted line (7). Small changes in the position of the animal's eye were observed to give large changes in the standing wave ratio.

(h) The variable attenuator was reset to give the original reading on the monitoring power meter(16) corresponding to the desired power level (see step (d)).

(i) For the duration of the experiment, the frequency, power level and standing wave ratio were monitored using, respectively, the wavemeter (17), power meter (16) and slotted line(7).

IV

MICROWAVE CATARACTOGENESIS IN ANIMALS

Young rabbits, weighing approximately 2 kilograms, were anesthetized by means of intravenous sodium nembutal. The left eye was taped open and the animal was placed in a holding box with its head protruding over a v-shaped cut-out. The iris termination of the C-band waveguide was covered with a 3 mil sheet of flexible, transparent polyethylene plastic. The rabbit's eye was centered in contact with the plastic covered iris termination plate. The cornea of the exposed eye could be protected from drying by applying a slow drip of saline solution onto its surface while the protective covering of plastic prevented any of this solution from entering the waveguide. When the eye was properly positioned, the microwave irradiation was initiated.

Following irradiation, both the control right eye and exposed left eye were examined ophthalmologically and the lenses were photographed with the Zeiss Retinal Camera.

The purpose of these preliminary experiments was to develop a sound investigative methodology. It was not to obtain definitive data; which, by necessity, would require a large scale program. Therefore the objective was to produce cataracts by exposure to precisely defined fields of microwave radiation in order to determine the applicability of our methods for biologically assaying the cataractogenic effects.

For this reason, it was decided that exposure levels should be sufficiently intense to produce immediately discernible lens injury after a period of radiation lasting less than one hour. The cataractogenesis produced in this manner would be greater than threshold.

Exploratory exposures at average power levels below 100 mw/cm^2 (both pulsed at 5515 MC and cw at 5512 MC) for 60 minutes did not produce acute injury of the lens. In order to insure the occurrence of cataractogenesis and to test the flexibility of the exposure apparatus, average power levels of at least 500 milliwatts were generated under the following conditions:

C-band Frequency	Average Power	Peak Power	Average Power Density	Peak Power Density	Exposure Time	Modulation Envelope
MC/sec	mw	watts	mw/cm^2	w/cm^2	minutes	
5512	1000	1.0	790	0.79	15	cw
5512	500	0.5	390	0.39	37	cw
5442	500	500.	390	390.	34	✓
5442	730	730.	580	580.	15	✓

✓ 200 pps, .001 duty cycle, 5 μsec pulse length

These exposures resulted in acute lens changes which progressed to cataract formation and demonstrated the feasibility of this exposure technique. The results for cw and pulsed exposures at the same power density (390 mw/cm^2) for approximately the same time appeared to be similar. At higher power densities, the results were more marked.

The experience gained from these preliminary experiments indicates not only that various microwave emission factors can be segregated and controlled but also that exact time-power relationships for cataractogenesis can be determined by biological assay.

V

MICROWAVE CATARACTOGENESIS IN MAN

Ophthalmologically documented data has been accumulated concerning three unusual cases of cataracts which have developed in personnel working in microwave environments. These three men have been examined during different stages of the disease process and the information obtained from these examinations permits some understanding of microwave cataractogenesis in man.

There is a common history of repeated intimate exposures to high power densities of microwave radiation. This was not due to some spurious exposure from antenna reflections nor leaking waveguide joints. Instead, the exposures were due to looking directly into end windows of generating tubes or into small windows cut into waveguides. In all three cases, the eye was brought close to the source of radiation and the r-f fields were considerably greater than 10 mw/cm^2. As all of these cases were discovered after a time lapse and as all of the men worked with a variety of equipment, it is not possible to recreate the exact exposures that any of them received. However, it has been estimated, retrospectively, that exposures probably ranged from 350 mw/cm^2 to several $watts/cm^2$. The time duration of each exposure was estimated as several minutes and such exposures were repeated from many times daily to several times a week during a period of weeks to months. Typically, the visual sighting was performed with the right eye and shortly afterwards, each man noticed that his visual acuity of this eye was failing. One of the men suffered a rapid loss of vision and was removed from his environment for medical evaluation because he had developed a rapidly progressing cataract and so the vision in his left eye was spared. The visual loss in the other two men was slow, taking many months before being established, and by the time each was first examined, he had begun to use the left eye for his work because the visual acuity was better for this eye.

Of the five lenses so exposed, all five have developed cataracts. The sixth eye, which was relatively minimally exposed, has a minor defect in the posterior capsule (a thickening and opacification of a small area, approximately 1 millimeter in diameter) which is commensurate with the earliest changes noted in the human eye exposed to microwave radiation.

The ensuing photographs are taken from these cases and have been arranged to depict the sequence of cataractogenesis.

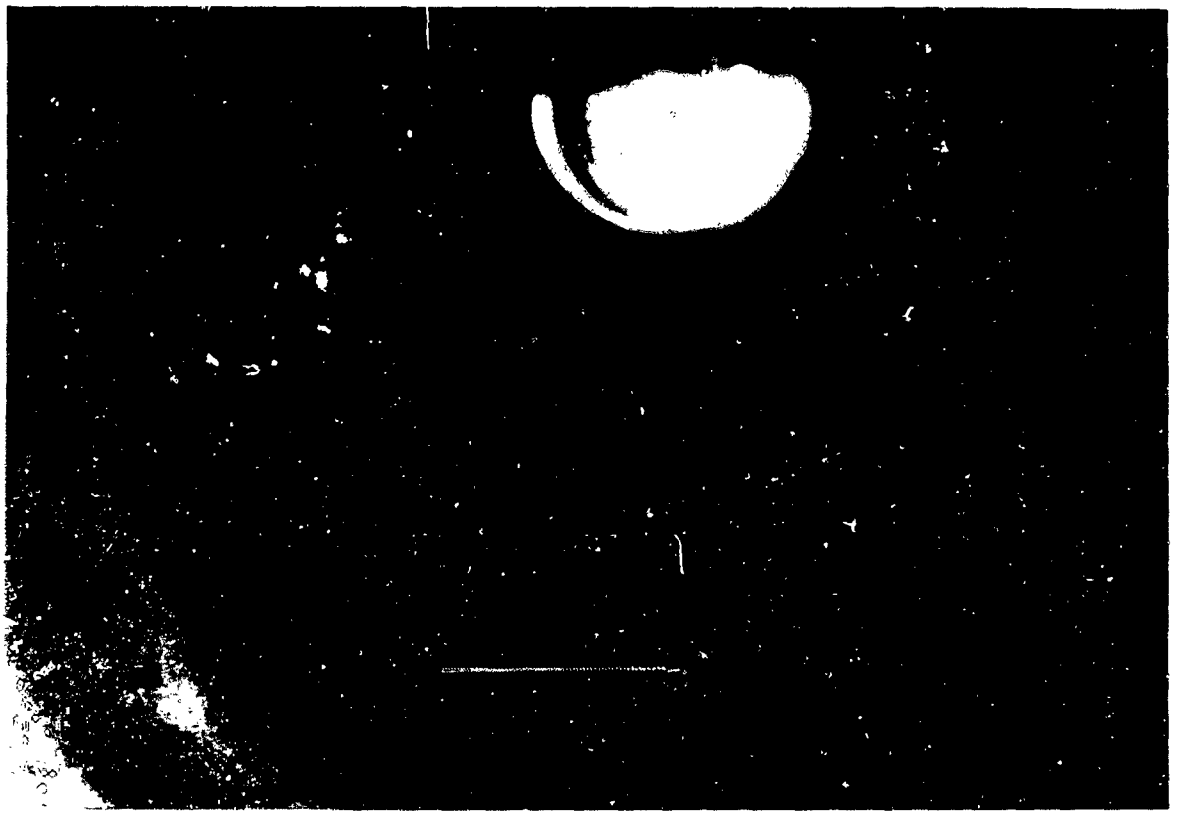


Figure 1

Figure 1 is a photograph of a normal lens to illustrate landmarks. The brush-like appearance at the top is due to the eyelashes of the upper eyelid. The bright white object in the center of the eyelashes is the reflection of the camera flash lamp from the anterior surface of the lens within the eye. Immediately below this, careful examination reveals the reflection of the camera flash lamp from the posterior surface of the lens. On one lateral edge of the photograph, a small portion of the iris can be recognized with its circumlinear pupillary margin. The main bulk of the photograph is the transparent ocular lens which appears to be black because it is optically empty and we are visualizing the darkness of the interior of the eye through the lens.

Figure 2

Figure 2 is a photograph demonstrating early opacification of the posterior capsule of the lens which can be recognised between the flash lamp reflexes. The lens substance itself is completely transparent and the opaqueness that is visible in the photograph is due to the opacification present entirely within the posterior capsule. Notice that the reflection of the flash lamp from the posterior surface of the lens has become intensified and yet it has lost its sharpness and appears out of focus.

Figure 3

Figure 3 is a photograph demonstrating further opacification of the posterior capsule. The opacification is irregular and in some areas it has a lacey pattern while in other areas it has a honey comb appearance. The reflection of the flash lamp from the posterior surface of the lens can no longer be recognized. The entire lens substance is still transparent.

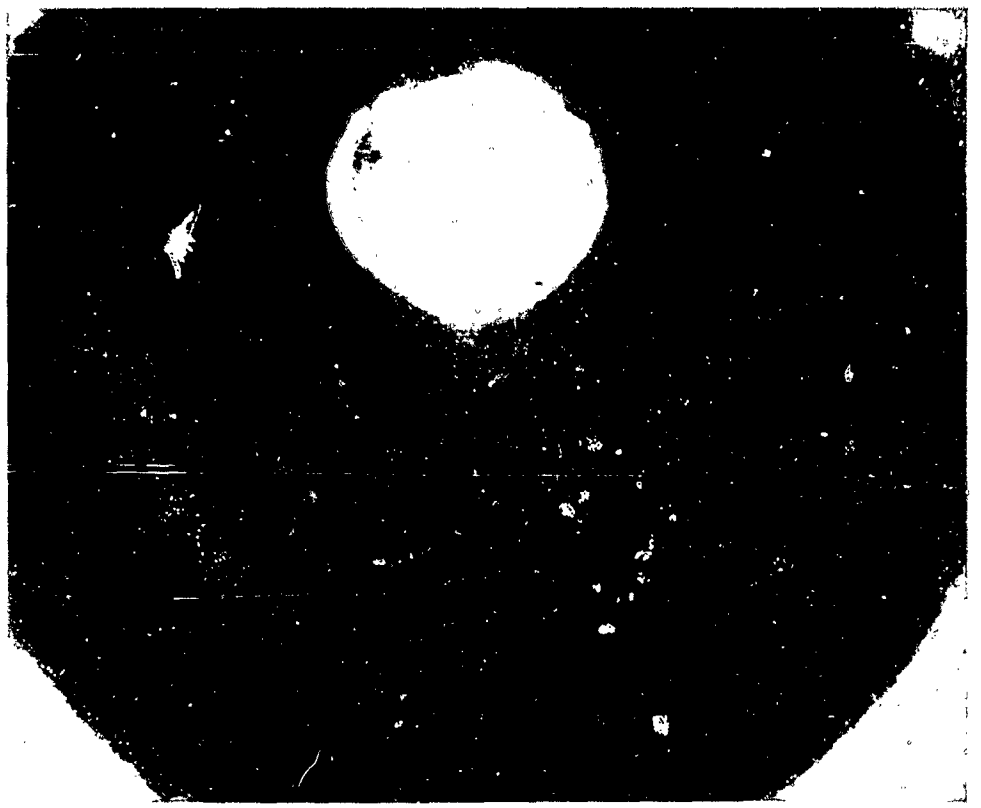


Figure 4

Figure 4 is a photograph demonstrating further opacification of the posterior capsule, concentric rings of opacification in the region of Eggert's line on the posterior capsule and extension of opacification to the equator of the lens. Even at this late stage of extension, the lens substance is still transparent. Shortly after this stage is reached, the lens substance becomes edematous and cataractogenesis proceeds rapidly.

Figure 5

Figure 5 is a photograph demonstrating an advanced stage of cataract formation. Although the entire lens substance is opaque, the heterogeneous nature of the opacification can be recognized, and it indicates that both intumescence and hypermaturity are present. The capsular opacification has extended to invlove the anterior capsule but this finding is obscured.

VI

DISCUSSION

Insofar as microwave cataractogenesis in man is concerned, a crude relationship can be established between the dose of microwave radiation delivered to the eye and the time of occurrence of cataract formation. Where the lens was believed to be exposed repeatedly to 5 watts/cm^2 energy density, the cataract was fully formed within two months. Where the lens was believed to be exposed repeatedly to 500 mw/cm^2, many months passed before the posterior capsular opacification appeared and many years passed before the cataract was fully formed. Needless to say, these estimates are based upon state-of-the-art approximations.

In addition to the cases mentioned above, several other microwave workers who have had known exposures to greater than 10 mw/cm^2 are under observation. None is believed to have been exposed to energy densities greater than 500 mw/cm^2. Although it is premature to report fully on this group, a small number of them exhibit early stages of thickening and opacification of the posterior capsule. None has yet lost any visual capability. However, due to the long periods of latency and slow progress of the pathology, it will be several years before a final determination of their cases can be ascertained.

Insofar as microwave cataractogenesis in the laboratory animal is concerned, all of the exposures reported here as well as practically all experiments reported in the literature have been on the basis of acute exposures. Even where exposures were performed in a repeated fashion with an interval of days separating succeeding exposures, this cannot be construed as other than a subacute exposure experiment. No experiment has involved chronic exposures. In addition, the vast majority of previous biological studies have suspect physical parameters due to the technical difficulties encountered when measuring a field of microwave energy. Moreover, all previous experiments were severely handicapped by the limitation of the microwave facility available to the investigator.

Mention has been made of the need to investigate the methodology of exposure in order to determine the differences inherent between acute, subacute or chronic application of the energy. It must be recognized that cataractogenesis also can follow an acute, subacute or chronic course.

VII

CONCLUSIONS

The parameter of personnel hazard associated with microwave environments is not fully delineated and the currently accepted permissible level of 10 mw/cm^2 energy density does not properly account for the many variables. Instead, it imposes restrictions uniformly for all microwave environments based upon an average power density without definition of time duration (although one may assume the intent of a 40 hour week).

At the time that this permissible level of exposure was adopted, it was less than any known harmful biological effect by at least an order of magnitude. In retrospect, that choice has proven to be a judicious state-of-the-art judgment for that point in time. However, it is evident that, today, a more sophisticated approach to defining the hazard can be employed. Under certain circumstances, it may become necessary to restrict the permissible level further; but, for most operational situations, it appears likely that the present restrictions are excessive.

The only manner in which the myriad of problems can be solved is to adopt a research program that will be meaningful not only insofar as controlled microwave radiation factors are concerned but also when the results of the investigations are related to man.

The project reported herein demonstrates the feasibility of performing such an applied research task.

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13 ABSTRACT

An exploratory investigation was performed to determine the applicability of spectrophotometric analysis to the measurement of cataractogenesis. It was found that standard spectrophotometric techniques cannot be utilized for this purpose but that a new method for performing spectrophotometry in the living eye, which is known as retinal reflection densitometry, shows promise of being capable of performing this task.

A methodology is presented for an applied research investigation of cataractogenesis in order to delineate the parameters of personnel hazard associated with microwave environments. The biological and microwave experimental protocols as well as the relationship of laboratory induced cataractogenesis to the clinical study of human microwave cataracts are discussed.

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